Accordingly, in a first aspect of the invention there is provided an apparatus providing and circulating to a medical device a medical gas mixture comprising at least two components, said apparatus comprising:-

a main gas circuit for recirculating the medical gas and comprising:-

a constant speed circulation pump for pumping gas through the main circuit and increasing the gas pressure from a lower pressure to a higher pressure,

a pressure maintaining valve downstream of the pump and dividing the main circuit into a higher pressure section and a lower pressure section,

a medical gas outlet in the higher pressure section,

a spent gas inlet in the lower pressure section,

a first feed gas supply inlet, preferably located in the higher pressure section,

a second feed gas supply inlet, preferably located in the higher pressure section,

a concentration determining means for measuring the concentration of at least one component of the recirculating medical gas mixture and generating a signal indicative of said concentration,

circuit volume regulating means for varying the volume of the main circuit at a location in the lower pressure section for maintaining a predetermined gas flow to the pump and generating a signal indicative of said volume, and

means for venting gas from the main circuit;

a first feed gas supply conduit for supply to the first feed gas inlet of a first feed gas of predetermined composition;

first feed gas supply flow control means for controlling the flow of first feed gas through the first gas supply conduit in response to the signal from the

concentration determining means to maintain constant the medical gas composition at the pump inlet;

a second feed gas supply conduit for supply to the second feed gas inlet of a second feed gas of predetermined composition different from the first feed gas;

second feed gas supply flow control means for controlling the flow of second feed gas through the second gas supply conduit in response to the signal from the circuit volume regulating means to maintain constant the recirculating medical gas composition; and

a medical device supply circuit for connecting the medical device to the main circuit to receive a portion of the medical gas from the medical gas outlet thereof and to return spent gas to the spent gas inlet thereof and comprising:

flow control means for controlling flow of the medical gas to the medical device and

purification means for removing contaminant(s) from the spent gas.

In another aspect, the invention provides a medical device system comprising a medical device connected to the medical device supply circuit of an apparatus of the first aspect *supra*.

Preferably, the pressure maintaining valve is a spill valve; i.e. a valve which opens wider in response to increased pressure to pass more gas into the lower pressure section and thereby maintain the pressure in the higher pressure section. However, the valve could be a conventional pressure reduction valve.

Preferably, the circuit volume regulating means comprises expansion bellows and the means for generating a signal indicative of the volume thereof suitable is an infra-red level or, preferably, ultrasonic sensor for detecting the level of the expansion bellows in an expandable direction thereof.

The apparatus preferably operates at a pressure of up to about 250 mbarg (125 kPa) through the main circuit, more preferably up to about 150 mbarg (115 kPa) and may provide gas to the medical device at a pressure of up to about 100 mbarg (110 kPa), but preferably about 30 mbarg (103 kPa). The circulation pump may circulate gas through the circuit at a rate of up to about 80 litres per minute (l/min), preferably up to about 30 l/min, more preferably from about 15 to about 20 l/min and preferably supplies gas to the medical device at a rate of up to about 30 l/min, preferably up to about 10 l/min and still more preferably up to about 5 l/min.

Each of the first and second fed gas supply flow control means may be, for example, a valve or, preferably, a mass flow controller (MFC).

The concentration determining means measures the concentration of one or more individual components of the gas mixture.

If required, the gas concentration determining means and/or the circuit volume regulating means can provide a respective signal to alert an operator, for example, by way of an alarm, to the need to manually adjust the relevant supply flow control means.

Communication of the concentration determining means or circuit volume regulating means with the supply flow control means may be via an analog electrical circuit, on which the gain may be set as desired. For example, for control of a supply of a gas, such as oxygen, which is rapidly consumed and/or urgently required by the medical device, the analog circuit may have a high gain. Conversely, for control of a supply of a relatively slowly consumed gas, such as xenon, or inert, such as nitrogen, the analog circuit may have a low gain.

When the medical gas mixture is a binary gas mixture, typically the concentration of only one component is measured and the corresponding signal used to control the feed of that component to the respective feed inlet with the

feed of the other component, or of a predetermined mixture of the two components, being controlled by the circuit volume regulating means signal.

When the medical gas mixture is a tertiary gas mixture, it is possible to operate in similar manner to a binary gas mixture using a separate feed for a first component and a mixed feed for the other two components optionally also with an amount of the first component. More usually, the three components at least primarily will be provided by three separate feeds. The concentration of two of the components can be measured and the individual concentration measurement signals used to control the corresponding respective feeds and the feed of the third component controlled by the circuit volume regulating means signal. Alternatively, the concentration of two of the components can be measured, one of the individual concentration measurement signals being used to control the corresponding feed and both the other concentration measurement signal and the circuit volume regulating means signal being used to control the feeds of the other two components.

For example, using a tertiary mixture of 40% oxygen, 20% xenon and 40% inert gas (usually nitrogen), feed control to maintain the gas composition can be achieved by using an oxygen concentration measurement signal to control the feed of oxygen and the circuit volume regulating means signal used to control the feed of a mixture of xenon, inactive gas and optionally oxygen. However, such a system does not allow full control in the presence of, for example air leaks or other events that affect only one of xenon and the inert gas and not the other. Accordingly, it is preferred to use three input gases, for example, (a) oxygen, (b) xenon or a mixture of xenon with a minor proportion of oxygen and (c) nitrogen or a mixture of nitrogen with a minor proportion of oxygen, and to control the flow rates of these using a tri-gas control system. A tri-gas control system can compensate not only for oxygen uptake by the medical device, but can also compensate, without error, for xenon and/or nitrogen uptake or emission by/from the device, dead volume filled with gas mixture or air, and leaks of air or other gases into or out of the system.

The tri-gas control system can be implemented by a straightforward proportional algorithm driven by two gas concentration signals and the system volume signal. For example, the oxygen can be added in an amount dependant on the difference between the measured and a predetermined oxygen concentrations; the xenon (or xenon/oxygen mixture) added in an amount dependant on the difference between the measured and a predetermined xenon concentrations; and the nitrogen (or nitrogen/oxygen mixture) added in an amount dependant on the extent to which the volume in the main circuit differs from a predetermined volume. However, in order to be assured of a stable control system where the different gas additions to not interact in a deleterious way, it is preferred to use both the difference in measured and predetermined xenon concentrations and between actual and predetermined circuit volumes to control the addition of both the xenon- and nitrogen- containing feeds. In particular, the xenon-containing feed is determined by the function YF, where: F = M' x (actual circuit volume – predetermined circuit volume), Y = M" x (actual xenon percentage concentration – predetermined xenon percentage concentration) and M' and M" are constant gain/multiplier factors, and the nitrogen-containing feed is determined by the function (A -Y)F, A is the maximum flow signal to the nitrogen-containing supply control means. Thus, if the gas supply control means are all MFCs having a 5V for 1 litre/min flow rate, the gain/multiplier factor for oxygen is 250, M' is 50 and M" is 35, (a) a measured oxygen concentration 2% low relative to the datum level, would result in the addition of 1 litre/min of oxygen; (b) a circuit volume 10% below the datum level would provide an F value of 5; and (c) a measured xenon concentration 2% low relative to the datum level would provide a Y value of 0.7. Thus under these conditions the YF signal would be 3.5, resulting in the addition of 0.7 litre/min of the xenon-containing gas, and the (A-Y)F signal would be 1.5 (A = 5), resulting in the addition of 0.3 litre/min of the nitrogen containing gas.

Preferably the medical device is an artificial ventilator or, especially, a cardiopulmonary bypass oxygenator. The apparatus of the invention can selectively supply an artificial ventilator or a cardiopulmonary bypass oxygenator,

whereby a patient can readily be ventilated immediately before and after cardiopulmonary bypass.

In a third aspect of the invention, there is provided a method of providing a medical device with a medical gas mixture comprising at least two components, said method comprising:-

recirculating the medical gas mixture in a main circuit having a higher pressure section maintained at constant pressure in series with a lower pressure section;

withdrawing a portion of the medical gas mixture from the higher pressure section and feeding said portion to the medical device;

removing contaminant(s) from the spent gas mixture from the medical device and returning the decontaminated spent gas to the lower pressure section;

replenishing components in the medical gas mixture by addition of feed gases to maintain the recirculating medical gas composition constant; and

varying the volume of the main gas circuit to maintain the gas flow therein.

Preferably, the method comprises operating a medical device system in accordance with the second aspect of the present invention.

In a fourth aspect of the invention, there is provided a method for the extracorporeal treatment of blood by contacting blood with a recirculating medical gas mixture in a device provided with the medical gas mixture using the method of the third aspect of the invention.

The gaseous composition for use in the present invention preferably contains at least one high value gas, which it would be beneficial to recover after use in the process. Such gases include the noble gases, especially xenon, krypton and neon or isotopes thereof, or stable isotopes of gases such as oxygen and carbon dioxide.

In a preferred embodiment, the gaseous composition comprises xenon, preferably in an amount of at least about 10% by volume, more preferably at least about 30%, still more preferably at least about 50% and still more preferably at least about 70% by volume. Most preferably, the gaseous composition comprises xenon in an amount of about 80% by volume.

The gaseous composition preferably also comprises oxygen and more preferably consists predominantly of xenon and oxygen. Most preferably, the gaseous composition comprises xenon and oxygen in a ratio of about 80% to about 20% by volume and usually will consist solely of xenon and oxygen.

The component gases may be replenished individually or in a mixture of gases, preferably a binary mixture, of known relative proportions.

Optionally, the gaseous composition may also comprise, for example, helium or nitrogen. Helium may be provide through a further supply flow conduit from, for example, a helium cylinder or a cylinder containing a helium/oxygen mixture. Nitrogen may be provided, for example, by admitting air to the circuit.

In a preferred embodiment of the invention, the medical device is a cardiopulmonary bypass oxygenator and the gaseous composition is a mixture predominantly of oxygen and xenon. Preferably the component gases are supplied from a first gaseous supply comprising oxygen and a second gaseous supply comprising xenon, which may be a xenon/oxygen mixture, for example in a ratio of about 80% to about 20%. Preferably the first gaseous supply is oxygen and the second gaseous supply is a xenon/oxygen mixture.

When oxygen is relatively quickly consumed, by a patient connected to the medical device, the oxygen concentration determining means, which may be, for example, an oxygen fuel cell sensor, preferably is connected to the first supply flow control means by a high gain electronic circuit enabling relatively rapid replenishment of oxygen to the circuit. For example, every 1% difference

between the desired concentration and the detected concentration of oxygen may correspond to a flow through the oxygen (first) supply conduit of 1 litre per minute (l/min). Conversely, for controlling the concentration of xenon, which is relatively slowly consumed by a patient connected to the medical device, a low gain response may be more appropriate.

It is preferred that the concentration of xenon in a recirculating binary mixture with oxygen is determined with an ultrasonic gas analyser. Preferably, the ultrasonic gas analyser has an ultrahigh frequency ultrasonic transmitter, for example greater than 100 kHz. A suitable ultrasonic gas analyser is that described in our co-pending UK Patent Application No. 0210021.2 filed 1st May 2002 and the corresponding PCT Patent Application of even date with the present application (file reference: P8942WO).

The ultrasonic gas analyser may be used in combination with monitoring the recirculating volume to provide other information such as the concentration of contaminants in the circuit.

Similarly, comparison of the measured concentration of oxygen and xenon, in the recirculating gas, may provide information on the concentration of contaminants such as nitrogen or carbon dioxide.

When xenon or other high value gases are used, it is preferable to direct spent or recirculating gas that may from time to time be vented into a gas recovery space. Where the high value gas is provided from a supply in a fresh gas space in a container having an ullage space, the ullage space may provide the gas recovery space. Such a container can be as described in our co-pending UK Patent Application No. 0210022.0 filed 1st May 2002 and the corresponding PCT Patent Application of even date with the present application (file reference: P8943WO).

One or more of a carbon dioxide absorber, a carbon dioxide analyser and a pressure relief device can be provided downstream from the medical device when carbon dioxide is a waste product from that device.

The following is a description by way of example only and with reference to the accompanying drawings of presently preferred embodiments of the invention. In the drawings:

Figure 1 is a diagramatical representation of an apparatus according to one embodiment of the present invention for providing a xenon/oxygen mixture to a cardiopulmonary bypass oxygenator;

Figure 2 is a diagramatical representation of a ventilator circuit for introduction into the apparatus of Figure 1 to replace the cardiopulmonary bypass oxygenator;

Figure 3 is a diagramatical representation of another ventilator circuit for introduction into the apparatus of Figure 1 to replace the cardiopulmonary bypass oxygenator; and

Figure 4 is a diagramatical representation of an apparatus according to another embodiment of the present invention for selectively providing a xenon/oxygen mixture to a cardiopulmonary bypass oxygenator and an artificial ventilator.

With reference to Figure 1, xenon/oxygen mixture in a ratio of 80% xenon to 20% oxygen is fed into the main circuit 102 of the apparatus (generally designated 101) from a xenon/oxygen supply in fresh gas space 119 of container 121 via xenon mass flow controller (MFC) 123.

The oxygen content of main circuit 102 is topped up from oxygen cylinder 125 via regulator 127 and oxygen mass flow controller (MFC) 129.

One or more (preferably four) diaphragm pumps 117 pump the xenon/oxygen mixture around the circuit 102 at a rate of up to 20 litres per minute (l/min) at a pressure of up to 150 millibar gauge (115 kPa).

The gaseous composition is fed to cardiopulmonary bypass (CPB) oxygenator 103 via medical device supply conduit 105, which is regulated by flow control valve 139, which may be set at a desired level by the operator.

CPB oxygenator 103, which is typically a membrane oxygenator, is fed unoxygenated blood from a patient 107 via unoxygenated blood conduit 109 and returned to the patient 107 via oxygenated blood conduit 111. Spent gas from the CPB oxygenator 103 is fed through spent gas return conduit 113 and then through water trap 147 and primary carbon dioxide absorber 135 to return to the main circuit 102 upstream of pump(s) 117.

Gas passing through the spent gas return conduit 113 and medical device supply conduit 105 pass through respective bacterial filters 115 to protect the patient 107 from contamination from the apparatus 101 and vice versa.

In order to ensure that a constant flow of gas at the set pressure is supplied to the oxygenator 103 and thus available to the patient's blood, gas circulates through the main circuit 102 via pressure maintaining valve 141 downstream from the outlet to medical device supply conduit 105. Pressure maintaining valve 141 is a valve which allows gas flow only when the pressure exceeds a predetermined level, for example 30 mbarg (103 kPa) and accordingly maintains a constant pressure between the pumps 17 and the valve 141.

Downstream from the pressure maintaining valve 141, the gaseous composition is analysed for xenon content using ultrasonic xenon analyser 143 of the kind described in our co-pending UK Patent Application No. 0210021.2 filed 1st May 2002 and the corresponding PCT Patent Application of even date with the present application (file reference P8942WO). In an alternative arrangement (not shown) the xenon analyser is located upstream of the pressure maintaining valve 141.

The gas is then fed via bellows 145, which expand to take up any additional volume of gas in the apparatus or contract to compensate for loss of volume in the apparatus, and receives the spent gas upstream of pump(s) 117.

The oxygen concentration in the main circuit 102 is monitored by an oxygen fuel cell sensor 131 that is shown situated in the main circuit 102 downstream from pump(s) 117 but could be located downstream of the pressure maintenance valve 141. The gas is then fed through backup carbon dioxide absorber 133, which removes residual carbon dioxide from the recirculating gas. The carbon dioxide removed by absorbers 133 and 135 has entered via the oxygenator 103 after being flushed from the patient's blood. At least absorber 135 should be replaced with each use of the system.

Downstream from the backup carbon dioxide absorber 133, a small sample of gas is drawn from the main circuit 102 and fed to analyser unit 137 to be analysed for carbon dioxide, via an infra red gas analyser, to ensure that the carbon dioxide absorbers are working efficiently and for oxygen, via a paramagnetic gas analyser, as a backup to the oxygen fuel cell sensor 131. The sample is returned to the main circuit 102 upstream from the pump(s) 117.

Recovery gas conduit 149 selectively feeds at least a portion of gas from the main circuit 102 at a point downstream from the backup carbon dioxide absorber 133 to the ullage space 151 of container 121, via recovery valve 153 and compressor 155. This container 121 is of the kind described in our co-pending UK Patent Application No. 0210022.0 filed 1st May 2002 and the corresponding PCT Patent Application of even date with the present application (file reference P8943WO).

An atmospheric vent 157 from bellows 145 enables the gas within the apparatus to be vented to atmosphere if desired.

There is a U-tube relief device 159 on the spent gas return conduit 113 to protect the oxygenator 103 and patient 107 in the event of any back pressure from the apparatus 101.

Addition of fresh gas to the apparatus is controlled by an analog electronic circuit (not shown) between oxygen fuel cell sensor 131 and oxygen MFC 129 for fresh oxygen addition and by an analog electronic circuit between an ultrasonic level sensor 146 measuring the position of the bellows and the xenon MFC 123 for fresh xenon/oxygen mixture addition.

As well as monitoring the concentration of oxygen in the main circuit 102, oxygen fuel cell sensor 131 enables the oxygen concentration to be controlled. The operator may choose a set point on the sensor 131 corresponding to the desired oxygen concentration. When oxygen concentration measured by sensor 131 falls below the set point, oxygen MFC 129 is triggered to feed fresh oxygen into the main circuit 102 at a rate proportional to the difference between the oxygen level set point and the oxygen sensor 131 measurement via a high gain circuit connecting oxygen MFC 129 to sensor 131.

Typically, the high gain oxygen control circuit (not shown) will have a gain of 1, corresponding to an oxygen flow rate through oxygen MFC 129 and into the main circuit 102 of 1 l/min for every 1% difference between the oxygen set point and the measured oxygen level.

The xenon concentration of the main circuit is controlled by ultrasonic bellows level sensor 146. The operator may set the desired level on a potentiometer (not shown) connected to sensor 146, which corresponds to an expanded level of the bellows 145. This level corresponds to the volume in the system and, given that the oxygen concentration is known, to a desired concentration of xenon. When the sensor 146 detects that the bellows 145 has fallen below the desired level, xenon MFC 123 is triggered to feed fresh oxygen/xenon mixture into the main circuit 102 at a rate proportional to the

difference between the potentiometer set point and the level measured by bellows sensor 146, via a low gain circuit (not shown) connecting sensor 146 to xenon MFC 123.

Typically, the xenon low gain circuit will have a gain of 0.1, corresponding to a flow of fresh xenon/oxygen mixture into the main circuit 102 of 0.1 l/min for every 1% difference between the potentiometer setpoint and the level measured by bellows sensor 146.

The various sensor readings and flow rates are displayed on a monitoring unit (not shown).

In use, oxygen is consumed and replaced by carbon dioxide via the CPB oxygenator 103. The operator may select the flow rate to the oxygenator 103 by using flow control valve 139. This effectively controls the rate that carbon dioxide is flushed from patient's blood into the apparatus and hence provides some control as to the relative acidity or alkalinity of the patient 107.

Carbon dioxide is absorbed by primary carbon dioxide absorber 135 and the reduction in the oxygen level is detected by fuel cell sensor 131 triggering, via the high gain circuit, replenishment of oxygen levels under the control of oxygen MFC 129.

Xenon sensor 143 measures the xenon concentration in the main circuit 102. This reading may be compared to other readings to reach various conclusions. For example, if the oxygen concentration measured by oxygen fuel cell sensor 131 does not equal 100 minus the xenon concentration measured by xenon sensor 143, it is indicative of contamination, for example by carbon dioxide or nitrogen, and the operator may be alerted to vent the apparatus to atmosphere or recover the used gas. Alternatively, this may be done automatically at a preset level. The xenon sensor 143 is also used to monitor the xenon concentration predicted from the level of the bellows. Similarly, if these two readings do not

agree, this may be indicative of too much carbon dioxide, nitrogen or oxygen. As a result, the operator may choose to vent to atmosphere or recover the used gas.

If the gas volume in the apparatus is increased, the level of bellows 145 increases. If the level of bellows 145 exceeds a preset level, gas is vented from the apparatus, again either manually or automatically, via atmospheric vent 157 and/or xenon recovery valve 153. Optionally, the sensor 146 may be connected to ultrasonic analyser 143 so that when the bellows 145 upper level is exceeded, vent 157 or valve 153 is selectively opened depending on the xenon content of the gas measured by analyser 143.

Referring now to Figure 2, a ventilator circuit generally designated 200 is connected at the filters 115 of the apparatus of Figure 1 to replace the CPB circuit. Fresh gas passes through the outlet filter 115 (see Figure 1) into the ventilator circuit 200 via a check valve 213 to provide gas to the ventilator thereby maintaining the oxygen and xenon concentrations in the ventilator circuit 200 at the required levels.

The ventilator circuit 200 includes a conventional ventilator 201 of the kind providing a positive drive gas pressure (above atmospheric pressure) in pulses for a second or two, followed by a slightly longer period at atmospheric pressure. The period, cycle time and power of the drive gas pressure is set, in conventional manner, to match the needs of the patient 205.

When the ventilator drive pressure is positive, it pushes gas out of the bellows of a bellows assembly 202 via a control valve 203 and a check valve 204 into the lungs of the patient 205. Valve 203 is a pneumatically operated valve that is held closed by the positive ventilator drive pressure during the inflation of the patient's lungs. When the ventilator 201 proceeds to the atmospheric pressure part of its cycle, which allows the patient's lung to relax and deflate, exhaled gas (oxygen removed, carbon dioxide added) flows from the lungs via a check valve 209 to a soda-lime absorber canister 210. The canister 210 absorbs carbon

dioxide from the exhaled gas and then allows it to flow back to refill the bellows of the bellows assembly 202. This gas may then be pumped back to the patient's lungs by the bellows during the next positive pressure pulse from the ventilator 201. The level of carbon dioxide in the gas from the patient's lungs is measured continuously by a CO_2 analyzer 207, which monitors both the end-tidal (peak) CO_2 level, which gives an indication of the patient's correct respiration, and the minimum CO_2 level, which gives an indication of exhaustion of the soda-lime 210.

When the ventilator 201 is in the atmospheric pressure part of its cycle, the valve 203 is open and, if the bellows inside the bellows assembly 202 has reached the top of its travel and the gas pressure becomes positive enough (a few millibar), gas may flow from the bellows into an optional bag 211a, past an optional pressure relief valve 212a and back to the gas recycling circuit 102 (see Figure 1) via an outlet 208 and filter 115 (see Figure 1). The bag 211a and optional pressure relief valve 212a are needed if the tubing connecting the recycling circuit 102 to the ventilator circuit 200 are not large enough to assure correct operation of the bellows pressure relief via valve 203. In an alternative arrangement, the bag 211b and relief valve 212b are located upstream of the check valve 203.

Figure 3 shows an alternative ventilator circuit 300 for connection to gas main circuit 102 of Figure 1 in corresponding manner to the ventilator circuit 200 of Figure 2. It is specially designed to ensure that the patient 308 receives fresh gas from the main circuit 102 of Figure 1 and that the exhaled gas is not mixed with fresh gas but is fed back to the main circuit 102.

Fresh gas from the outlet filter 115 (see Figure 1) is fed to the ventilator circuit 300 at inlet 301. An optional feed bellows assembly 302 is connected downstream of the inlet and has a weight 303 to ensure that it runs at a small positive pressure, which is sufficient to feed gas through a check valve 304 to raise the bellows in a ventilator bellows assembly 305 when the drive gas pressure from ventilator 306 is atmospheric.

The ventilator 306 and bellows assembly 305 function in a similar way to that normally employed in prior art ventilator systems. Periodically, ventilator 306 applies positive (above atmospheric) gas pressure to the outside of the bellows in the bellows assembly 305, collapsing the bellows and forcing gas from inside the bellows through a check valve 307 to the lungs of the patient 308. The ventilator drive gas to the bellows is also applied to a pneumatically operated valve 309 to close it, so that all the gas from the bellows assembly 305 goes to the patient 308.

When the gas pressure from the ventilator 306 is relaxed back to atmospheric pressure, the bellows in bellows assembly 305 re-inflates with fresh gas from the inlet 301 and the feed bellows 302. The check valve 307 is biased with a spring or weight so that it only opens at a few millibar, assuring that 100% of fresh gas flows into the bellows assembly 305.

Simultaneously with the refill of the main bellows assembly 305 the patient's lungs relax, exhaling gas containing less oxygen and more carbon dioxide relative to fresh gas. The exhaled gas flows through pneumatically operated valve 309, which is now open to the gas return circuit (since the drive gas pressure is atmospheric). The gas return circuit may optionally include a variable gas volume comprising an additional bellows or flexible bag 310.

The embodiment of Figure 4 is similar to that of Figure 1 but provides for the selective supply of the xenon/oxygen mixture to an artificial ventilator and a CPB oxygenator so that xenon can be administered to the patient before, during and, if desired, after surgery. Many of the components of the embodiment of Figure 4 correspond to those of Figure 1 and accordingly have been identified by reference numerals in the 400 series corresponding to those in the 100 series used in Figure 1. Only the main differences between the two embodiments will be described.

In the embodiment of Figure 4, the xenon/oxygen mixture is provided by a

conventional cylinder 419 instead of the ullage-space container 121 of Figure 1 and no provision is made for recovery of xenon. Further, the oxygen fuel cell sensor 431 is provided downstream, instead of upstream, of the pressure maintaining valve 441. A water adsorber 471 is provided immediately downstream of the primary carbon dioxide absorber 435 and a carbon dioxide analyzer 472 is provided to monitor the carbon dioxide content of the spent oxygenator gas.

A ventilator supply conduit 460 regulated by flow control valve 461 connects the main circuit 402 downstream of the pumps 417 to an essentially conventional artificial ventilator assembly via a bacterial filter 463. The artificial ventilator assembly comprises the ventilator 463, bellows 464, oxygen fuel cell sensor 465, carbon dioxide absorber 466, carbon dioxide analyzer 467 and endotracheal tube 468 and operates generally as described with reference to Figures 2 and 3. The spent gas from the artificial ventilator assembly is returned to the main circuit via ventilator spent gas return conduit 469, including a bacterial filter 470, connected to the primary carbon dioxide adsorber 135.

Although illustrated and described herein with reference to certain specific embodiments, the present invention is nevertheless not intended to be limited to the details shown. Rather, various modifications may be made in the details within the spirit and scope of the following claims.